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Climate Change Projections for *Picea engelmannii*

Report for

Spruce Beetle Epidemic and Aspen Decline Management Response EIS

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Background

This report provides projections for changes in distribution of climatically suitable habitat for *Picea engelmannii* (Engelmann spruce, hereafter referred to as spruce) between the reference period (1961-1990) and the decade surrounding 2060, as well as a suggested strategy for adaptation of spruce forests to climate change.

The GMUG and surrounding area have gotten warmer, and continued warming is expected (Barsugli, 2009). Maximum temperatures have increased in recent decades. Although there has been no major trend in Gunnison River stream flow over past 60 years, there has been a trend towards earlier snowmelt and peak stream flow. This means a longer growing season and a corresponding higher water requirement to sustain healthy forests.

Scenarios developed for western Colorado using IPCC SRES Emissions Scenario A2 (medium-high emissions), compared to the reference period 1980-1999, project an increase in summer temperatures for the period 2040-2060 of 5.4 F (moderate scenario) to 7.0 F (extreme scenario) (Mearns and Barsugli, 2009). Most research for mid-latitude locations indicates the greatest temperature change should be at high elevations, where spruce-fir forests tend to occur. Projections for annual precipitation range from a 10% decrease to no change. As noted above, even the most optimistic precipitation projection could mean severe moisture stress with longer, substantially warmer summers.

Climate Change and Spruce

A bioclimate model for spruce covering the western USA was prepared by Rehfeldt et al. (2006). Correspondence between the occurrence of spruce predicted by the model and the range map was strong. The model accurately predicted the occurrence of isolated populations such as those in the Chiricahua Mountains of southeast Arizona and in the Sweetgrass Hills of Montana.

General circulation models were used to apply future climates to the bioclimate model and project changes in climatic suitability for spruce (Rehfeldt et al., 2006). A loss of 47% in area of suitable habitat was projected for the decade around 2060, and a loss of 72% for 2090. Only 23% of the habitat was expected to persist in place through 2100.

Based on discrepancies between occupied and optimal climates, the responses of spruce to climate change are generally expected to be strongly negative (Rehfeldt et al., 2004). However, many climatypes of the species have been identified, and with assisted migration using climate-based seed transfer guidelines, populations may remain viable into the future (Rehfeldt, 2004).

Engelmann spruce seedlings were found well above tree line in the early 1980s in the Front Range of Colorado (Daly and Shankman, 1985). Seedling occurrence was more than occasional, and the highest seedling found was 50 m (164 ft) vertically above tree line. Because dead seedlings were uncommon, the authors concluded that this was not a steady-state condition and that the upper tree line was moving upward.

Classifying Spruce Habitat by Change in Climate Suitability

Management approaches will vary with the anticipated impacts of climate change in a project area. Thus, it is necessary to classify spruce habitat geographically on this basis. Management can then be tailored to these habitat zones. The decade surrounding 2060 was selected as a target timeframe. In a similar modeling effort focused on aspen, we used four zones. However, with spruce, the middle two were relatively small and we elected to use only three zones:

LOST HABITAT – future climate will be so unfavorable that spruce is unlikely to survive the century.

THREATENED/ PERSISTENT HABITAT – future climate is expected to be minimally favorable to favorable, at least through 2060.

EMERGENT HABITAT – areas outside current distribution that will become climatically suitable.

The classification methods we followed are based on Rehfeldt's bioclimate model (Rehfeldt et al., 2006). The bioclimate model was initially developed by taking as input hundreds of thousands of locations with known presence or absence of *Picea engelmannii,* and used regression trees to associate presence or absence with long-term mean climate variables from the reference period, 1961-1990, at each location. In this way, the climate values that are associated with presence of spruce were determined.

Then the model was provided with a continuous grid of climate variables and asked to rate the climatic suitability of each cell for spruce. The grid we used (Crookston and Rehfeldt, 2008) is 0.0083 degrees, which is about 800 m (0.5 mile) wide at our latitude. Based on thousands of randomized model runs, the output is a grid of "vote" percentages. A grid cell with very few votes is extremely unfavorable and has very low chance of having spruce; while high votes indicate a climate suitable for spruce and high likelihood of having it.

The bioclimate model provided a distribution of votes in the reference period that closely follows the known distribution of spruce on a west-wide scale (Rehfeldt et al., 2006). When we examined the model in the context of the distribution of spruce on the GMUG, we found that areas with high votes had a high likelihood of having spruce, but areas with relatively low votes still had moderate likelihood of having spruce. This discrepancy arose because the west-wide data used for training the model did not have a representative sample of the spruce distribution on the GMUG.

To improve the results, the model was rebuilt using only local data. A 1-km grid of points was prepared and attributed with presence or absence of spruce based on the FSVeg Spatial (vegetation) polygon layer. We also created centroid points of each vegetation polygon and added those to the database. The presence of spruce in a polygon was based on spruce being one of the top three species in either Major Life Form or Dominant Life Form. Finally, additional points outside the GMUG boundary known or highly likely to not have spruce were added, for a total of 101,160 points. Based on these points the model was recalculated. The "confusion grid", indicating errors of omission and commission in classifying points in the database, showed very high accuracy (Table 1).

Table 1. Performance of the GMUG-based spruce bioclimate model on points of known presence and absence using a threshold of 50% votes to predict presence. Errors of commission are 1.2%; errors of omission are 0.06%.

	Model prediction	
Actual presence	Absent	Present
Absent	65,464	789
Present	21	34,886

A problem we encountered in trying to map these predictions arises from the differences in accuracy in the climate estimates available for the data points derived from vegetation polygons of fine scale and the relatively coarse scale climate grids of Crookston and Rehfeldt (2008). These differences in scale meant that the model was capable of predictions of greater accuracy than we are capable of mapping at the present time. To alleviate this problem, climate grids would have to be developed for GMUG using DEMs of finer scale than the 1 km DEMs available from Crookston and Rehfeldt. This is beyond the scope of the present applications of the model.

Therefore, we used a vote threshold of 35% to indicate suitable (≥ 35%) and unsuitable (<35%) climate, rather the 50% threshold used earlier (Rehfeldt et al., 2006). It was chosen because it corresponded well with actual spruce presence (Fig. 1) and left behind much of the spruce existing in very small pockets that cannot be captured by the coarse scale of the current climate maps. While increasing errors of commission, this lower threshold reduces errors of omission (saying a site is unsuitable when spruce is present) and is thus more conservative in projecting loss of suitability.

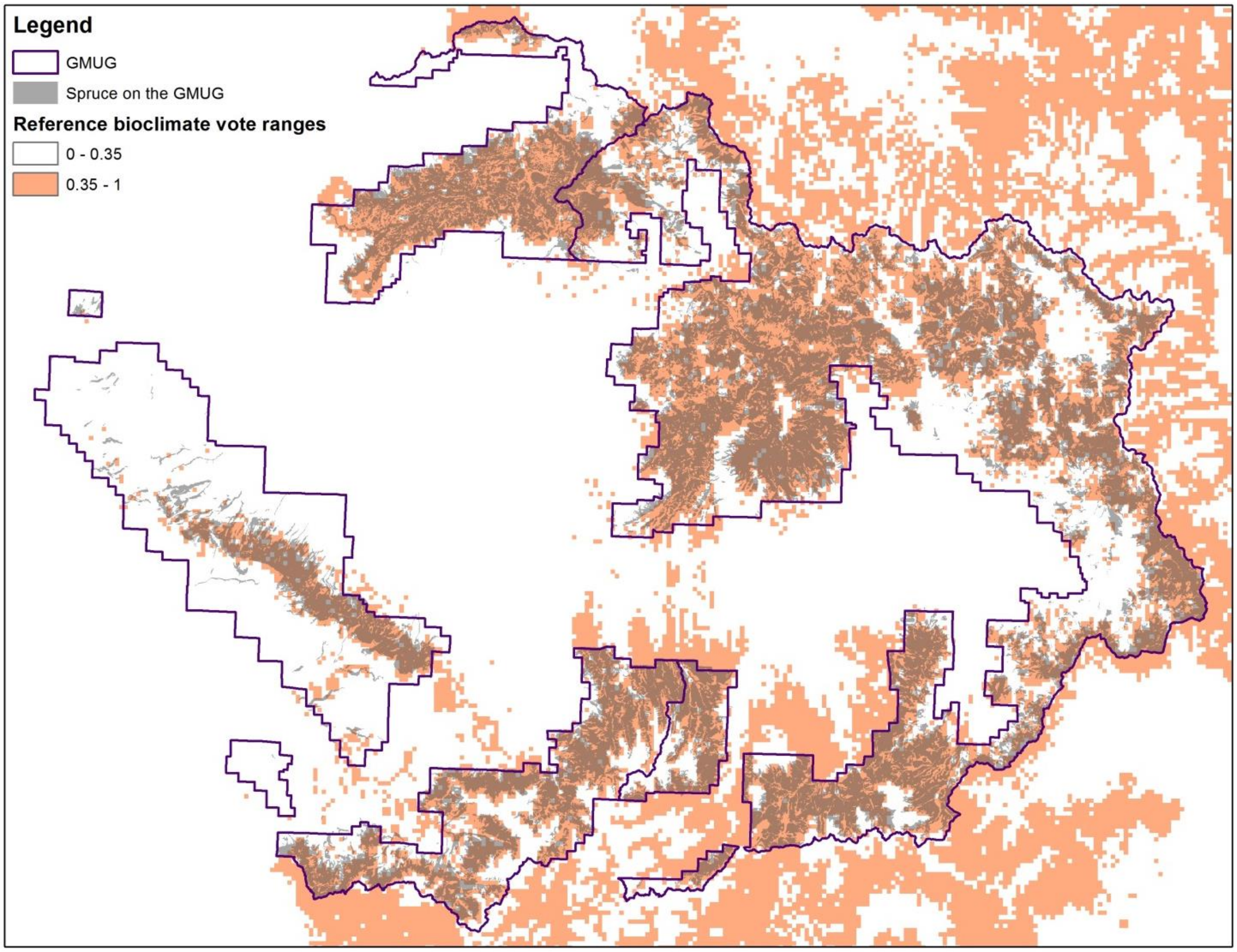

Figure 1. Votes of the bioclimate model during the reference period, split at the 35% threshold for suitability. Cover types containing spruce are shown in translucent gray (only within the forest boundary). Cells with votes ≥ 35% accurately predict spruce presence. However, because of the coarse scale of the model grid, some small and narrow polygons with spruce are not captured.

Downscaled climate projections from general circulation models (GCMs) were then used as input for the bioclimate model. Such climate projections are based in part on greenhouse-gas-emissions scenarios. Three representative GCMs and the A2 scenario from the IPCC Assessment Report 4 (AR4) were used with the spruce bioclimate model in earlier publications. In the work for this EIS, we used a newer emissions scenario that was developed and used for IPCC AR5, called RCP-6.0. Although officially no RCP (representative concentration pathway) is considered more likely than another, this one is the middle of the three RCPs that are considered within the realm of possibility and represents a moderate scenario. It is more conservative than the A2 scenario used earlier: it results in projection of substantially lower global temperatures than does A2 (Rogelj et al., 2012).

Running the bioclimate model with the climate projections for the decade surrounding 2060 resulted in a grid of cells with votes representing future suitability. We compared that to suitability in the reference period (1961-1990) by subtracting votes in the two periods. The results (Fig. 2) indicate decreasing climatic suitability on the Uncompahgre Plateau, the West Elk Mountains, on the fringes of the Grand Mesa, and along the northern fringes of the Cochetopa and Cebolla Creek watersheds, south of Blue Mesa Reservoir. Increases in suitability were seen mostly at high elevations.

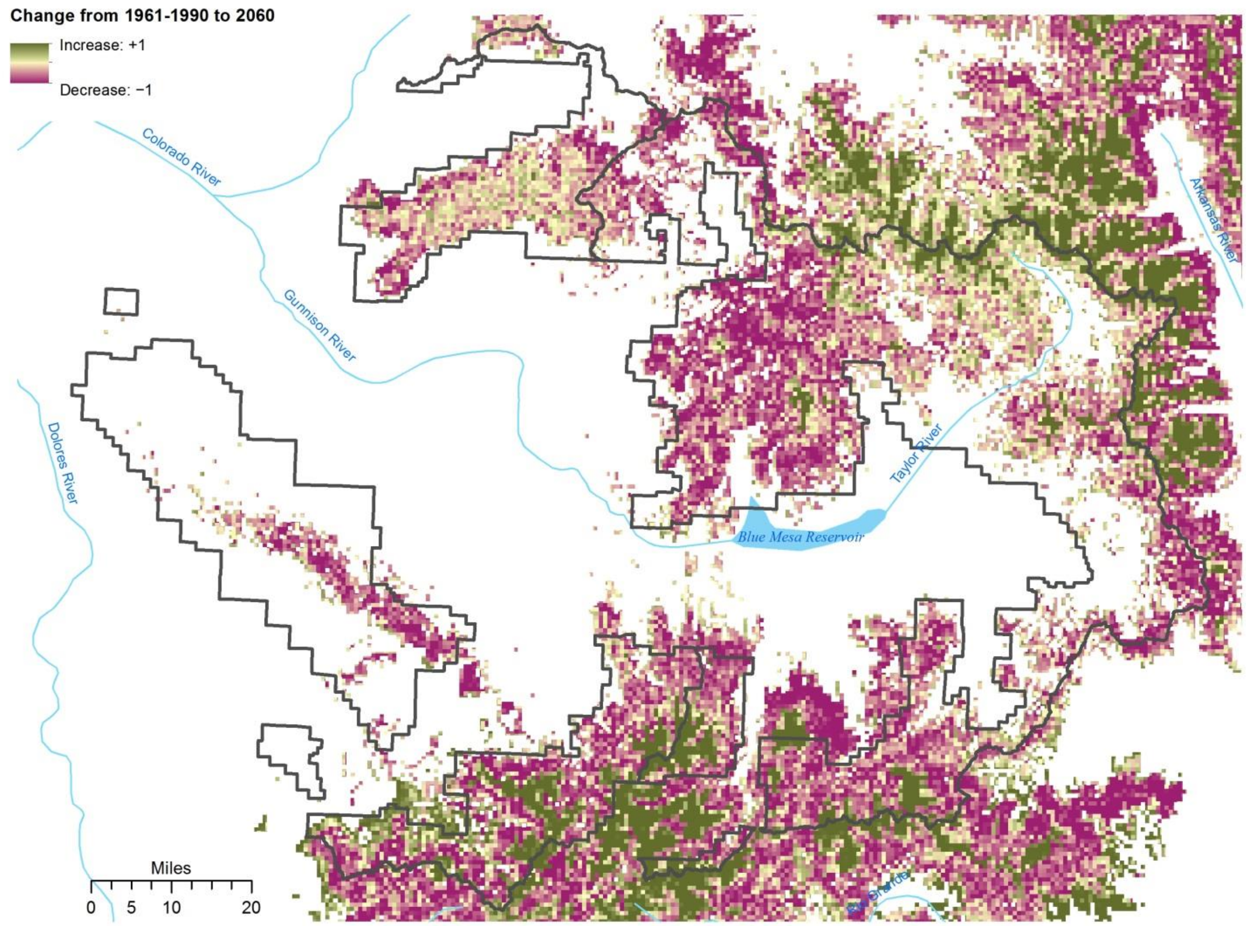

Figure 2. Projected change in climatic suitability for spruce between the reference period (1961-1990) and the decade surrounding 2060. Maroon indicates decrease in suitability; green an increase. Based on the GMUG spruce bioclimate model (G.E. Rehfeldt, RMRS) and climate projections using the RCP-6.0 carbon scenario in three general circulation models (GCMs); map is the average of the three projections. Grid cells with votes < 35% in both time periods are not shown.

LOST habitat is defined as grid cells with votes ≥ 35% in the reference period, and < 35% in 2060. The EMERGENT zone is comprised of grid cells with votes < 35% in the reference period, and ≥ 35% in 2060. The remaining spruce habitat had votes ≥ 35% in both periods. Because this was not a very large area and generally did not occur in large blocks, we did not split it into THREATENED and PERSISTENT zones, as we did with aspen.

The model projects no habitat suitable for spruce on the Uncompahgre Plateau, and substantial loss in the West Elks and east of the Grand Mesa (Fig. 3). Except for the fringes, much of the Grand Mesa is in the relatively uncertain THREATENED/PERSISTENT zone. The zones are mixed in the rest of the GMUG, where topography and elevation are varied.

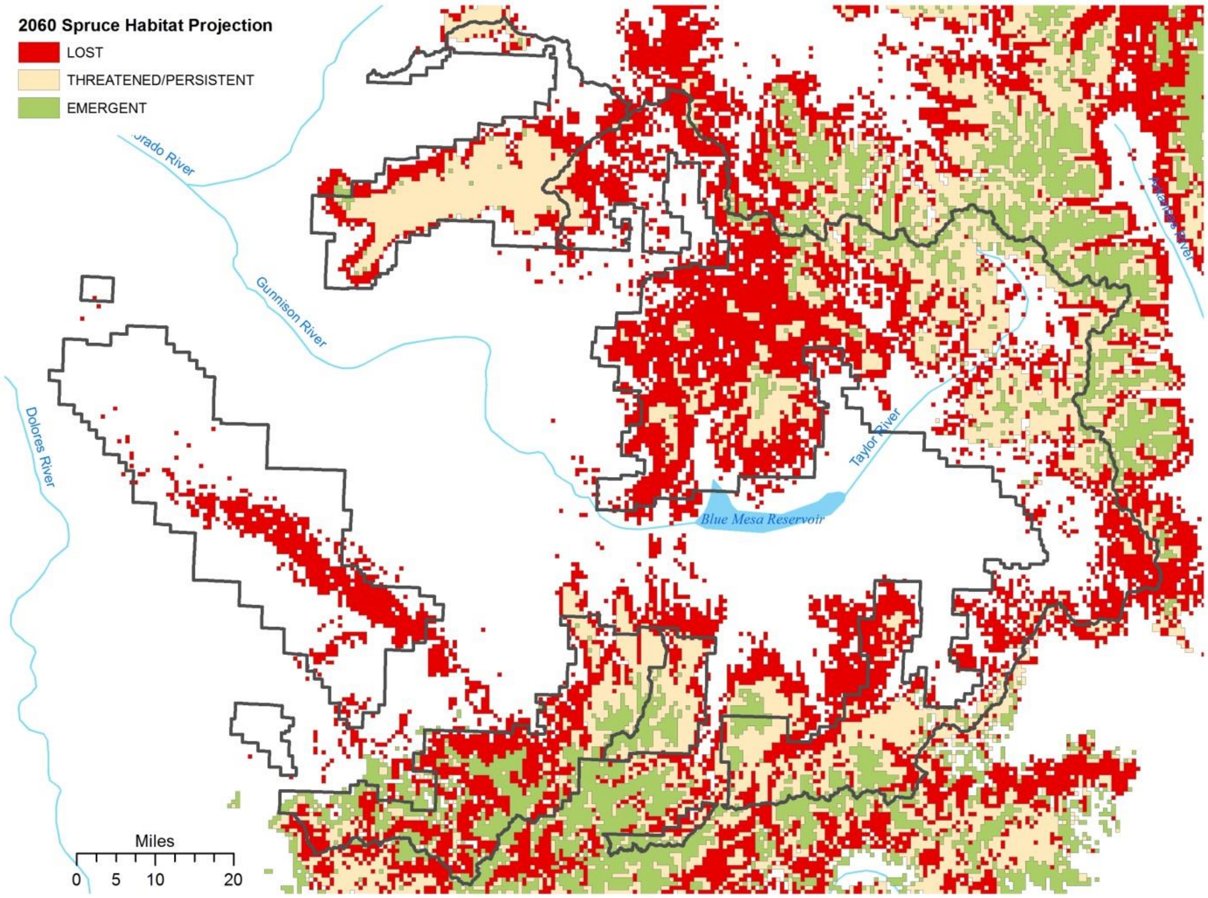

Figure 3. Future climatic habitat zones of Engelmann spruce.

Future Condition: No Action

Projected changes in suitability. By the latter half of the century, given the climate projections, and even with moderate CO_2 scenarios, substantial portions of the GMUG are likely to be climatically unsuitable for spruce. The LOST zone represents these areas, including Uncompahgre Plateau, much of the West Elks, the area east of the Grand Mesa, and south of Blue Mesa Reservoir, on the northern edges of the Cochetopa and Cebolla Creek watersheds (some of which is outside the forest boundary).

In the THREATENED/PERSISTENT zone, given the uncertainty in the model, we cannot say with much confidence how much of that zone will be inhospitable to spruce by 2060. However, we can say with reasonable confidence that suitability will decrease in most of that zone, and that climatic conditions will continue to become less suitable through the rest of the century.

The model projects significant area in the Emergent zone, which will become climatically suitable to spruce. There are likely other limiting factors in much of this area, such as unstable slopes and lack of soil. Where suitable site conditions occur within that zone, seedlings may gradually start establishing at higher elevations, as has been observed in the Front Range (Daly and Shankman, 1985).

Forest responses. Numerous studies have concluded that projected rates of climate change are faster than rates of response in natural systems (e.g., Davis et al., 2005). Very long time lags in migration and adaptation of forests to these changes will be the outcome of a "let nature take its course" approach to managing for climate change. The long history of provenance testing and studies of forest disturbance tell us what we need to know about the fate of existing forests -- rapid or gradual demise from a variety of biotic and abiotic agents as trees become less and less attuned physiologically to the climate where they are rooted.

The result can be viewed as ecological havoc. Dependence on natural processes will result in long-term lack of many amenities and services that humans expect from natural ecosystems.

A Strategy for Adaptation of Spruce to Climate Change

Adaptation Tactics

Lower BA/density. Where management is planned in established stands, targeting a lower basal area than usual is likely to increase drought resilience and is often recommended as an adaptation tactic (Innes et al., 2009; Peterson et al., 2011). In a group-selection management system, this could be accomplished by harvesting larger groups, but thinning in the residual matrix is likely to be more effective where it is practical. This is also a recommendation for reducing long-term susceptibility to spruce beetle.

Climate-based seed-transfer guidelines. Proactive management for climate-change adaptation includes planting trees. Maintaining forest health and productivity requires planting trees in the climates for which they are genetically suited. That means assisted migration, moving seed sources upwards into climates that are projected for the near future.

Wherever spruce is planted, which ideally would occur primarily in the THREATENED/PERSISTENT zone, seed transfer guidelines that are designed for climate change should be used. Although such guidelines are not fully developed, the regional geneticist recommended planting a mix from lower-elevation zones. With the help of experts such as Gerald Rehfeldt and Mary Mahalovich, the GMUG could develop and use its own seed transfer guidelines based on information already available (Rehfeldt, 2004).

Favor warm/dry species. In the LOST zone and on dry sites in the THREATENED/PERSISTENT zone, favoring or planting of species tolerant of warm/dry conditions should be considered. These will vary in different parts of the GMUG, but lodgepole pine, blue spruce, Douglas-fir, and aspen are potential candidates in these areas.

Tailoring Current Management to Future Habitat Zones

LOST HABITAT – Management intended to perpetuate and/or improve spruce-fir forests in the LOST zone is generally not recommended. Favoring or planting of warm/dry species can be considered here. However, given the coarseness and uncertainty in the model, it may be wise to continue to manage for spruce on particularly good, moist sites in the LOST zone.

THREATENED/ PERSISTENT HABITAT –

- Investments in replacing beetle-killed spruce forests with spruce should be considered primarily in the THREATENED/PERSISTENT zone, especially on the better sites. Shade cards or other measures can be used to ameliorate warm, dry conditions and increase success of seedling establishment. Climate-based seed-transfer guidelines should be used if available.
- On other sites in this zone, planting should ideally include or even be dominated by one or more warm/dry species.
- Management of established forests should consider whether reduction of basal area and density is feasible to increase drought resilience.

EMERGENT HABITAT – Where soils occur, planting of spruce seedlings in the EMERGENT zone can be considered. At this stage, plantings should not be more than a few hundred feet in elevation above existing spruce forests. As time goes on (beyond the timeframe of this EIS), that range can be extended.

Climate Change and the Current Spruce Beetle Epidemic

The current spruce beetle epidemic may provide several advantages in helping spruce-fir forests to adapt to climate change:

1. **Opportunity for change**. The widespread mortality provides an opportunity for changing forest types in areas that are expected to become unsuitable for spruce, by favoring or planting species better suited for warm/dry conditions. Many areas will require forest renewal to maintain forest health, growth, and productivity (Rehfeldt et al., 2014).
2. **Genetic adaptation**. Where spruce seedling are or will soon be abundant, they provide a rich source of genetic diversity that will be naturally selected for fitness in warmer/dryer conditions than their parents experienced. However, the range of this diversity in a local population is likely not enough to fully adapt to the changing climate.
3. **Developmental adaptation**. Individuals have some degree of morphological and physiological plasticity to adapt to their environment during development. Just as individual trees growing in a windy environment become more windfirm, individuals growing in a warm, dry environment usually develop deeper roots and have other traits to adapt to the conditions. Young trees will be better able to develop these traits than mature, established trees.

No Regrets

When considering strategies for adapting to climate change, a "no-regrets" strategy is one that is beneficial under multiple scenarios and has little or no risk of socially undesired outcomes (Vose et al., 2012). Such actions benefit resources and values regardless of climate-change effects. The present strategy is comprised of such actions. If future climate change is minimal, despite all the projections to the contrary, these actions will still facilitate continuation or replacement of forest cover and resilience to drought. If, on the other hand, climate change is more extreme than the projections used here, we will have done the best that we currently can to provide for the conservation of spruce genetic diversity.

Acknowledgments

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Appendix: Accuracy and Uncertainty in Modeling and Projections

It should be recognized that there are limits to the accuracy of the methods employed, and to the certainty attached to projections of the future. While the bioclimate model is quite effective at replicating the distribution of spruce at large scales, at smaller scales errors of omission (predicting absence where spruce occurs) and commission (predicting presence where no spruce occurs) can be seen. For examples, errors of omission may occur when spruce is present in a small, suitable microsite in a grid cell that has, on average, unsuitable climate. Although the best techniques were used, interpolating or downscaling climate information cannot replicate actual geographic variation in climate with complete accuracy. Climate projections are based on a representative carbon pathway (RCP, i.e., emissions scenario) that may not represent the actual future trend in greenhouse gases. For example, conditions projected for 2060 may actually occur sooner if emissions are higher than projected by RCP-6.0, or later if they are lower. For these reasons, although boundaries between future habitat zones must be precise for planning purposes, ideally they should be regarded as the best estimate of fuzzy boundaries, and the timing of the projected changes as likely but uncertain.